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# ADIABATIC CHARGING OF NICKEL-HYDROGEN BATTERIES

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# BACKGROUND

- ACTIVE BATTERY COOLING, DURING PRE-LAUNCH ACTIVITIES, IS DIFFICULT AND EXPENSIVE
- NICKEL-HYDROGEN BATTERY CHARGING, IN THE ABSENCE OF ACTIVE COOLING, WAS INVESTIGATED FOR APPLICATION DURING AXAF-I PRE-LAUNCH ACTIVITIES.
- TESTING WAS CONDUCTED TO
  - DEMONSTRATE THE FEASIBILITY OF THE "ADIABATIC CHARGING" APPROACH
  - PROVIDE A PARAMETRIC DATA BASE

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Battery management during prelaunch activities has always required special attention and careful planning. The transition from nickel-cadmium to nickel-hydrogen batteries, with their higher self discharge rate and lower charge efficiency, as well as longer prelaunch scenarios, has made this aspect of spacecraft battery management even more challenging.

The AXAF-I Program requires high battery state of charge at launch. The use of active cooling, to ensure efficient charging, was considered and proved to be difficult and expensive. Alternative approaches were evaluated. Optimized charging, in the absence of cooling, appeared promising and was investigated. Initial testing was conducted to demonstrate the feasibility of the "Adiabatic Charging" approach. Feasibility was demonstrated and additional testing performed to provide a quantitative, parametric data base.

# ADIABATIC CHARGING

## DEFINITION

- ADIABATIC CHARGING IS CHARGING IN THE ABSENCE OF COOLING
- HEAT DISSIPATED BY THE CHEMICAL PROCESSES IN THE CELLS, AS WELL AS  $I^2R$  HEATING, STAY IN THE BATTERY AND ITS TEMPERATURE INCREASES
- THE BATTERY HAS A LARGE THERMAL MASS
- THE ADIABATIC CHARGE METHODOLOGY INVESTIGATED FOR AXAF-I CONSISTS OF
  - CHARGING THE BATTERY, IN THE ABSENCE OF COOLING
  - MONITORING BATTERY TEMPERATURE,
  - TERMINATING CHARGE WHEN BATTERY TEMPERATURE REACHES 85° F

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The assumption that the battery is in an adiabatic environment during prelaunch charging is a conservative approximation because the battery will transfer some heat to its surroundings by convective air cooling. The amount is small compared to the heat dissipated during battery overcharge. Because the battery has a large thermal mass, substantial overcharge can occur before the cells get too hot to charge efficiently.

The testing presented here simulates a true adiabatic environment. Accordingly the data base may be slightly conservative.

The adiabatic charge methodology used in this investigation begins with stabilizing the cell at a given starting temperature. The cell is then fully insulated on all sides. Battery temperature is carefully monitored and the charge terminated when the cell temperature reaches 85° F. Charging has been evaluated with starting temperatures from 55° F to 75° F.

# SCOPE

- TESTING INCLUDED INVESTIGATION OF
  - ADIABATIC CHARGING
  - ADIABATIC TOP OFF CHARGING
  - VERY LOW RATE TRICKLE CHARGING
- TODAY'S PRESENTATION WILL COVER, PRIMARILY, ADIABATIC CHARGING TEST RESULTS
- DETAILS OF OTHER TEST RESULTS WILL BE REPORTED IN THE FUTURE.

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The overall AXAF-I battery test program, which is continuing, addresses several aspects of prelaunch battery management including charging, top off charging, open circuit stand, and low rate trickle charging; all in an environment in which there is little or no cooling. Parametric testing in the adiabatic charge mode has been completed and is reported in this presentation. Other results will be reported in the future.

# TEST PLAN

- PROOF OF CONCEPT: DEMONSTRATE ADIABATIC CHARGE CAPABILITY
  - CHARGE RATE: C/5, C/10, C/15, C/20
  - INITIAL TEMPERATURE: 55° F, 65° F, 75° F
  - RUN WITH RNH 65-5 CELLS (ON LOAN FROM EPI) WHICH ARE SIMILAR IN DESIGN TO THE AXAF-I BASELINE CELL
- PARAMETRIC TEST: CONFIRMATION AND DATA BASE DEVELOPMENT
  - CHARGE RATE: C/5, C/8, C/10, C/15
  - INITIAL TEMPERATURE: 60° F, 65° F, 70° F, 75° F
  - RUN WITH FLIGHT CONFIGURATION RNH 30-9 CELLS

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Adiabatic charging was addressed in a series of three tests.

A proof of concept test was run to demonstrate the feasibility of the approach. The test was run on RNH 65-5 cells which were loaned to us by Eagle Picher Industries. During the test, the thermal environment (e.g., adiabatic), the cell design, and the final charge temperature were fixed. Therefore the major test variables impacting charge acceptance were charge rate and initial charge temperature. Charge rate was varied over the range C/5 to C/20 which includes the lowest and highest rates deemed practicable during prelaunch activities. The initial-temperature range was constrained, at the low end by dew point considerations in the prelaunch environment, and at the high end by the fixed final charge temperature.

A parametric test was next run to validate the results of the proof of concept test and to provide a quantitative parametric data base. Test articles were flight configuration RNH 30-9 cells. The charge rate and initial charge temperature variable ranges were based on analysis of the proof of concept test results.

# TEST PLAN

CONT'D

- MISSION SIMULATION TEST
  - PRE-POST LAUNCH SCENARIO SIMULATION TESTING WAS PERFORMED AS PART OF A TOTAL MISSION SIMULATION TEST AT MSFC
  - THE POSTULATED SEQUENCE INCLUDED
    - = ADIABATIC CHARGING
    - = OPEN CIRCUIT STAND
    - = ADIABATIC TOP OFF
    - = C/500 RATE TRICKLE CHARGE
    - = DISCHARGE

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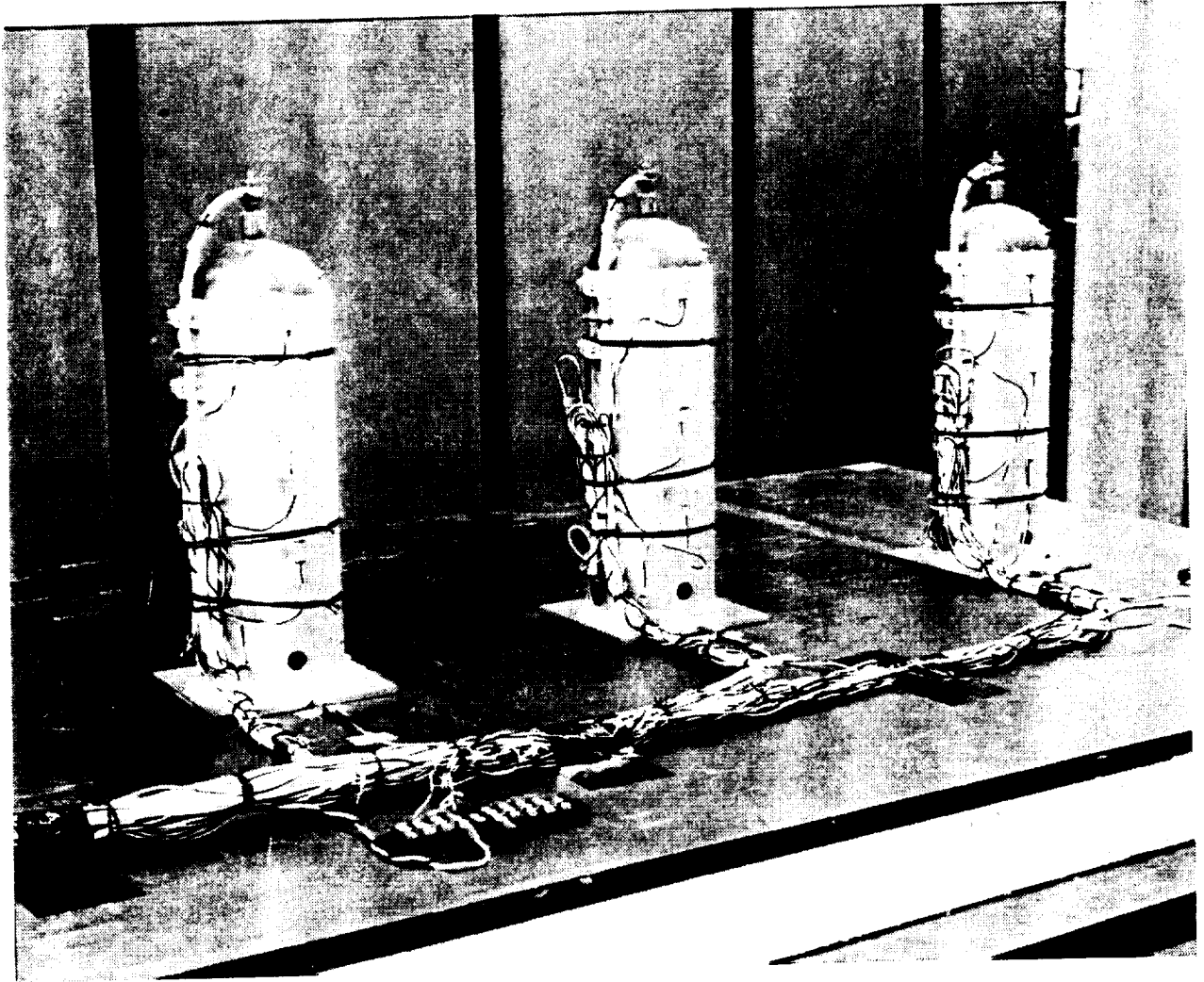
An AXAF-I mission simulation test is being run at MSFC. The test includes battery operation in a postulated pre-post launch scenario, as well as operation simulating on orbit cycling. Results obtained during operation in the simulated pre-post launch scenario are reported in this presentation.

# TEST ARTICLES

CELL PART NUMBER	RNH 65-5	RNH 30-9
RATED CAPACITY (Ah)	65	30
STACK CONFIGURATION	BACK-TO-BACK	BACK-TO-BACK
POSITIVE ELECTRODE	0.030", SLURRY	0.030", SLURRY
SEPARATOR	ZIRCAR, 2 LAYERS	ZIRCAR, 2 LAYERS
ELECTROLYTE (% , FINAL)	31	31
OPERATING PRESSURE (psi)	800	475
STRAIN GAUGE	YES	YES
TERMINAL CONFIGURATION	AXIAL	AXIAL
WEIGHT (gms)	1815	1010
PRECHARGE	POSITIVE	POSITIVE

The 30 Ah and 65 Ah cell designs differ only in capacity, weight/dimensions, and pressure. Electrode stack components, configuration, and electrolyte are identical.

## TEST CELLS ON COLD PLATE

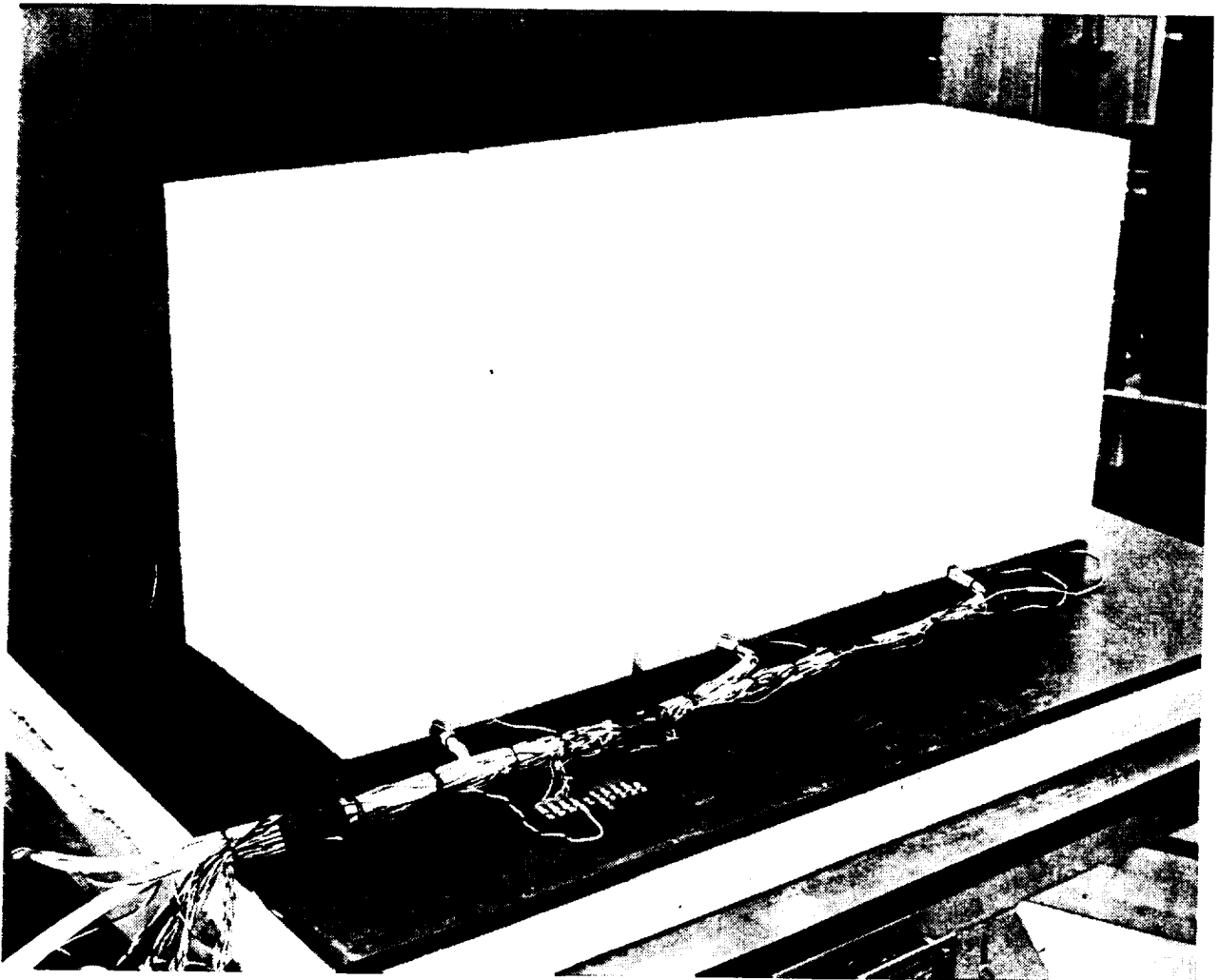


Individual cell instrumentation includes strain gauges for pressure measurement and thermistors at five locations from the top of the thermal sleeve to the sleeve base. In the configuration shown the sleeves are mounted directly to a thermally controlled cold plate. Ambient air and cold plate temperatures are also measured. Cell voltage, current, and pressure, as well as all temperatures are logged automatically. Data logging frequency is controlled by a slope sensing algorithm that increases the data logging frequency as the voltage and/or temperature rates of change increase.



# INSULATED TEST CELLS

## HEAT REJECTION TO COLD PLATE

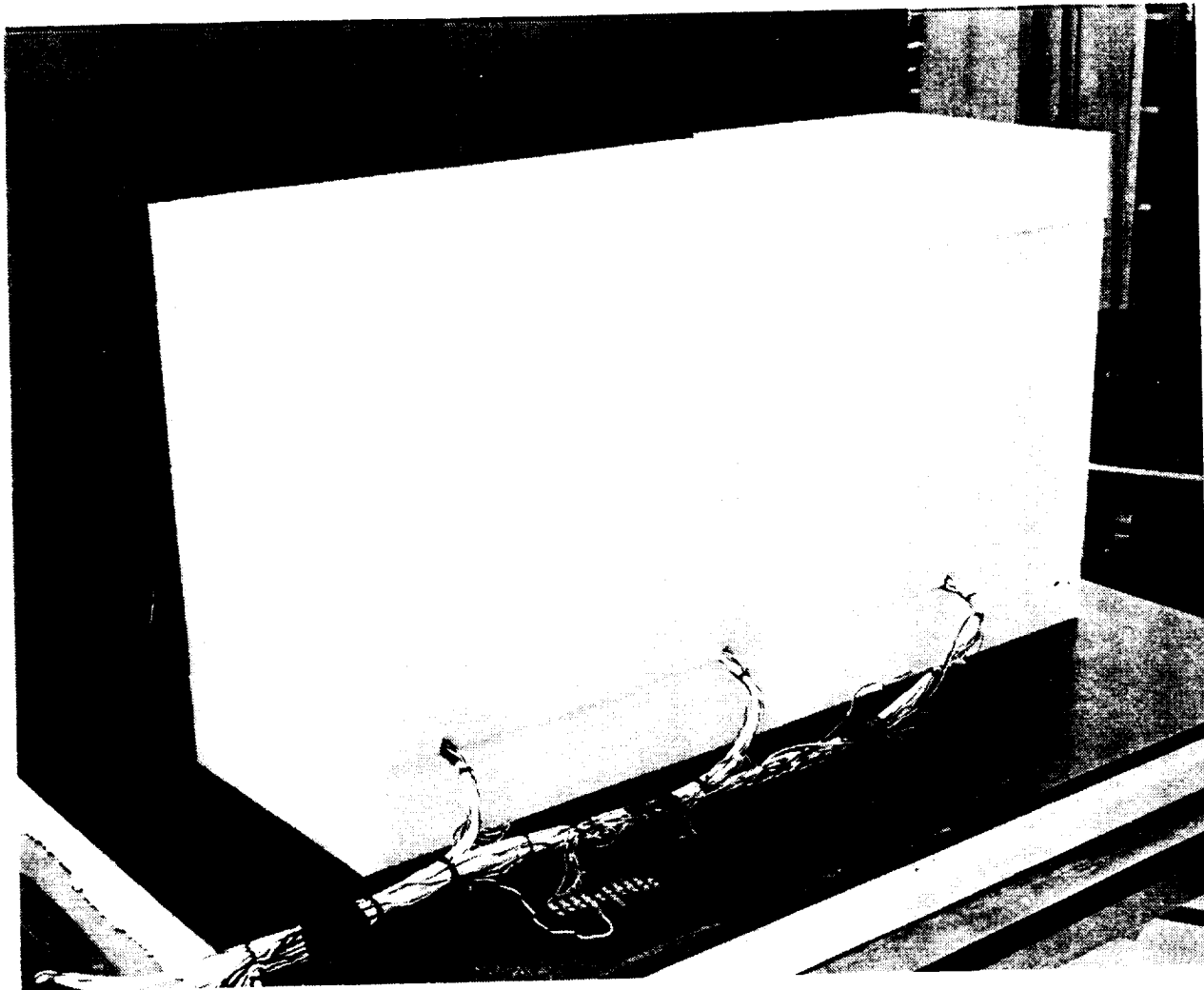


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In the configuration shown the cell sleeve base remains in contact with the cold plate and the remainder the cell-thermal sleeve assembly is insulated with three inch thick Ethafoam insulation. This configuration was used for all discharges.

# INSULATED TEST CELLS

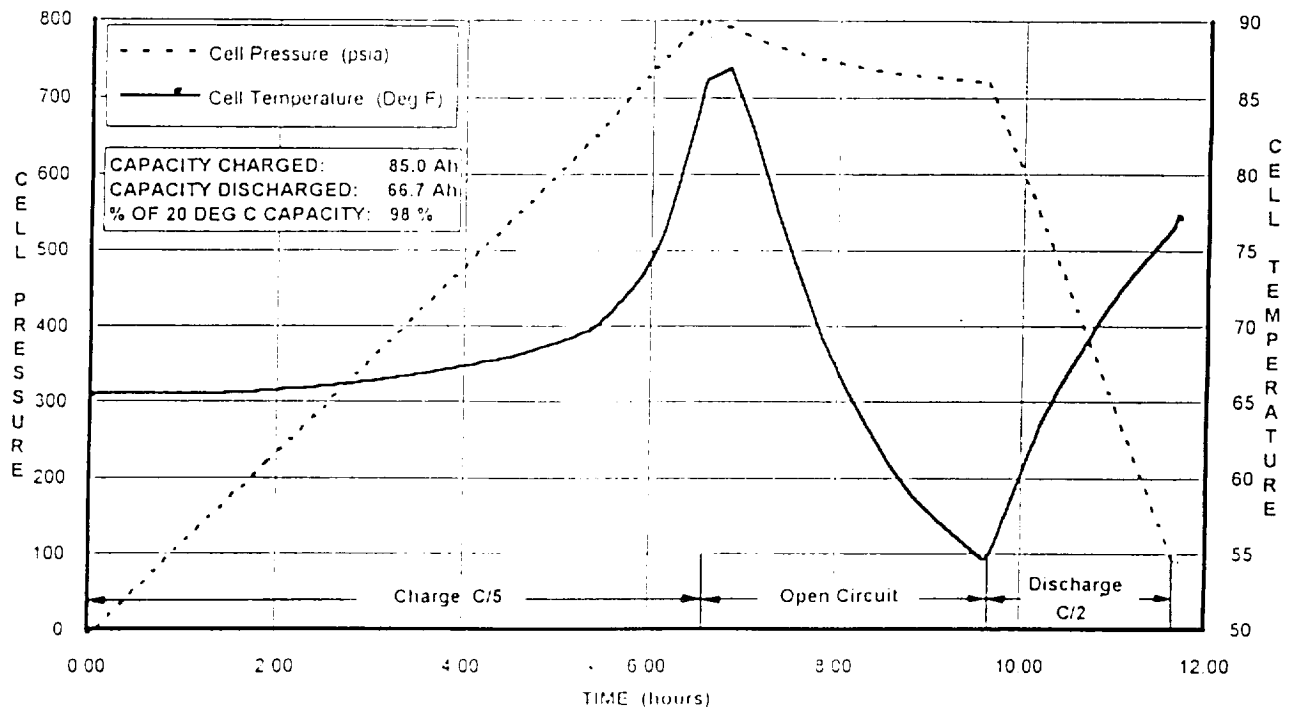
## ADIABATIC OPERATION



This configuration is similar to the previous one except that Ethafoam insulation is added between the sleeve base and the cold plate. The cell is thermally isolated. This configuration was used for all adiabatic operations.

# TYPICAL ADIABATIC CHARGE

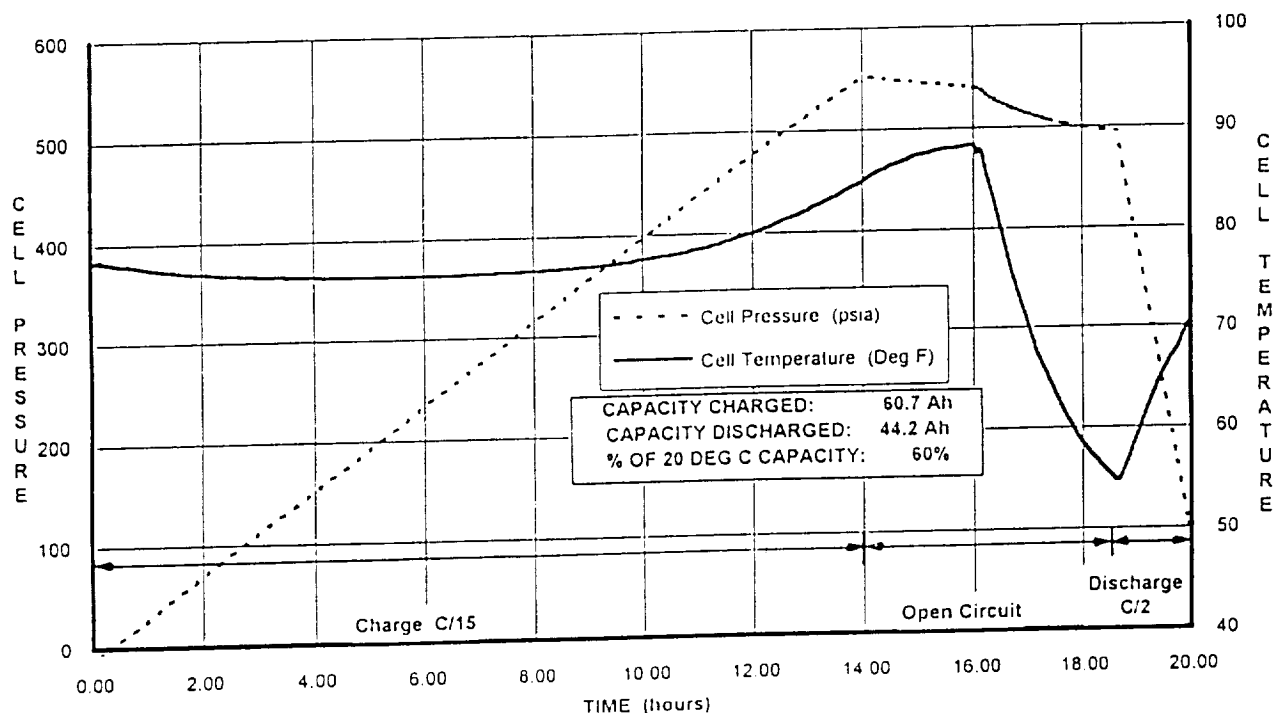
## 65° F, C/5 CHARGE RATE



This chart shows typical data logged during an adiabatic charge. Charge acceptance is tracked using cell pressure. The final discharge capacity is in excellent agreement with the capacity derived from pressure data. Charging was terminated at 85° F and overshoot took it to 87° F. The test configuration was changed from the fully-insulated cell to the configuration in which the baseplate is in contact with the cold plate. The cell was then cooled to 55° F and a standard C/2 discharge to 1.0 volt performed. The capacity discharged, 66.7 Ah, is 98% of the capacity recovered during a 68° F standard capacity cycle (16 hour C/10 charge at  $68 \pm 5^\circ \text{F}$ , C/2 discharge to 1.0 volt.) The recharge ratio, calculated as capacity charged divided by capacity discharged, is 1.27, which is acceptable for the small number of cycles occurring during prelaunch activities.

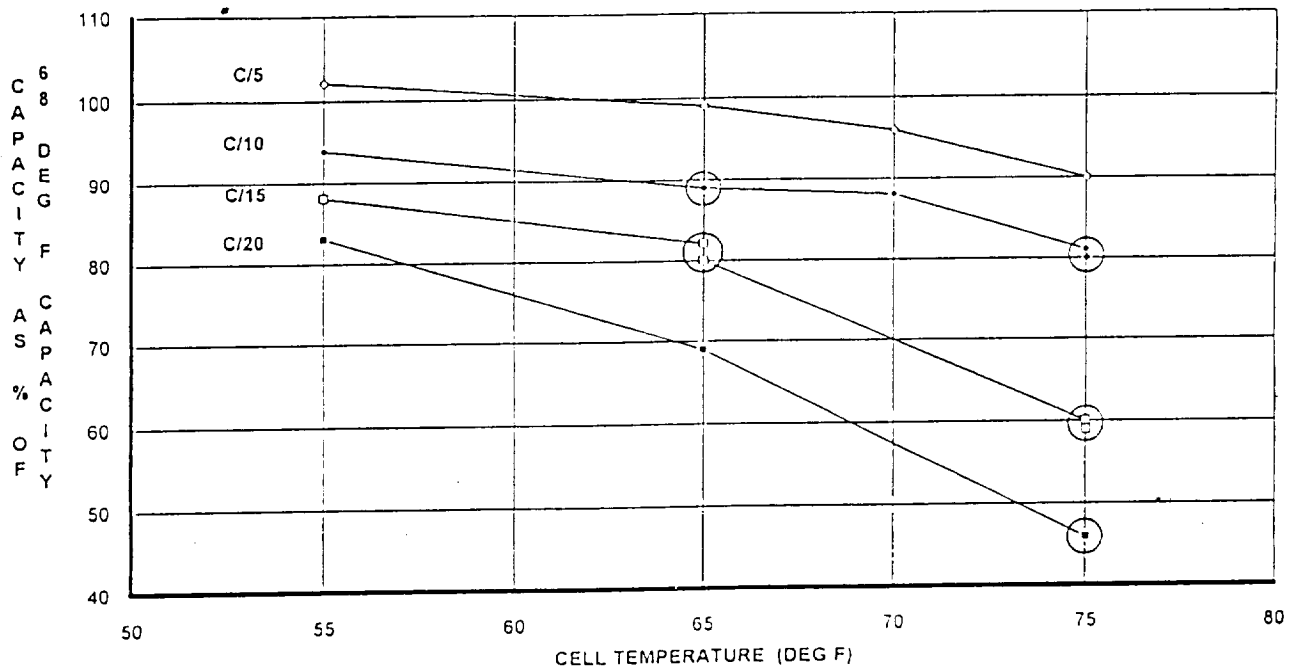
# TYPICAL ADIABATIC CHARGE

## 75° F, C/15 CHARGE RATE



The cycle shown on this chart is similar to the previous cycle except that the adiabatic charge was performed at 75° F and a C/15 charge rate. These are less efficient conditions and the capacity discharged, 44.2 Ah, is significantly lower than the 66.7 Ah recovered at the more efficient charge conditions of 65° F and a C/5 charge rate shown on the previous chart. Charge insertion was 60.7 Ah and the recharge ratio 1.37. Comparison with the previous chart indicates that, at 75° F and a charge rate of C/15, less charge is inserted and utilization of that charge is less efficient.

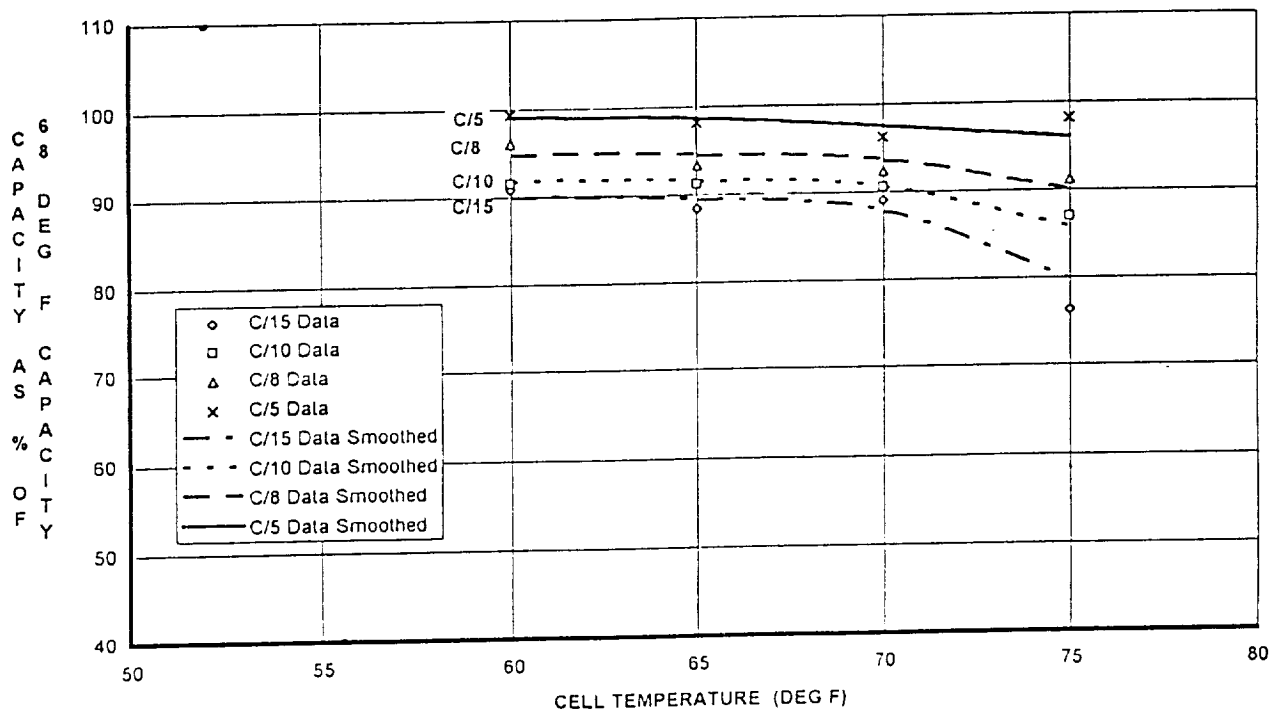
# CAPACITY EXPRESSED AS % OF 68 DEG F STANDARD CAPACITY 65 AH CELLS



Adiabatic charge results obtained with the 65 Ah cells are summarized as a family of curves showing the relationship between capacity, initial cell temperature, and charge rate. Capacity is expressed as per cent of standard 68° F capacity to allow comparison of cell lots with differing actual capacities. The circles indicate replicated data points.

These curves demonstrate that good charge acceptance is achieved, during adiabatic charging, provided charge parameters are maintained in efficient ranges.

# CAPACITY EXPRESSED AS % OF 68 DEG F STANDARD CAPACITY 30 AH CELLS



The adiabatic charge results obtained with the 30 Ah cells are summarized similarly and may be compared with the 65 Ah cell results. At conditions providing efficient charging, e.g., low initial cell temperature and high charge rate, the two sets of results are similar. However, when charge efficiency is lower, e.g., at higher initial temperatures and lower charge rates, the 30 Ah cells provide significantly higher relative capacities than the 65 Ah cells when both are charged adiabatically at the same conditions. The difference is attributed to the lower specific energy of the 30 Ah cell.

# ADIABATIC CHARGE

## EFFECT OF THERMAL MASS

- THE ADIABATIC CHARGE APPROACH WORKS BECAUSE THE BATTERY ABSORBS THE HEAT DISSIPATED AS THE CELLS GO INTO OVERCHARGE
- FOR A GIVEN DISSIPATION RATE: THE GREATER THE CELL MASS THE GREATER THE TOTAL CHARGE BEFORE THE CELL GETS TOO HOT TO CHARGE EFFICIENTLY
- THE DIFFERENCES IN ADIABATIC CHARGE ACCEPTANCE, BETWEEN THE 65 Ah and 30 Ah CELLS, CAN BE EXPLAINED BY THE RELATIONSHIP BETWEEN CELL WEIGHT AND CAPACITY, FOR THE 65 Ah AND 30 Ah CELLS
- CELL WEIGHT DIVIDED BY CAPACITY IS A CONVENIENT FIGURE OF MERIT TO COMPARE ADIABATIC CHARGE ACCEPTANCE RESULTS

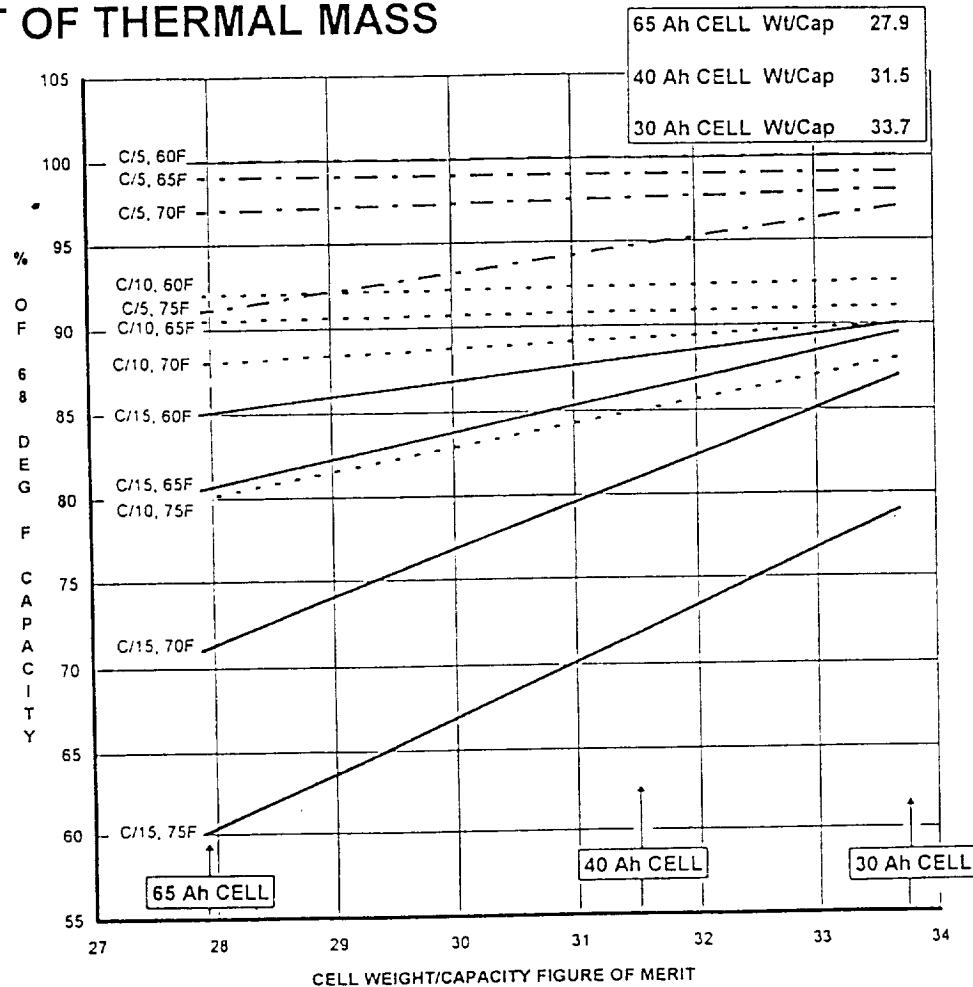
$$\text{FIGURE OF MERIT} = \frac{\text{CELL WEIGHT}}{\text{CAPACITY}} \frac{\text{gms}}{\text{Ah}}$$

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Because of its small size the 30 Ah cell is packaged less efficiently than the 65 Ah cell. The low operating pressure, 475 psi, is the maximum practical with this size and design. Another consequence of the difference in packaging efficiency is the difference in specific energy; 36 Wh/Kg for the 30 Ah cell and 43 Wh/Kg for the 65 Ah cell.

For a specific cell capacity and a given set of adiabatic charge conditions: the larger the cell mass the more charge accepted before reaching the charge termination temperature.

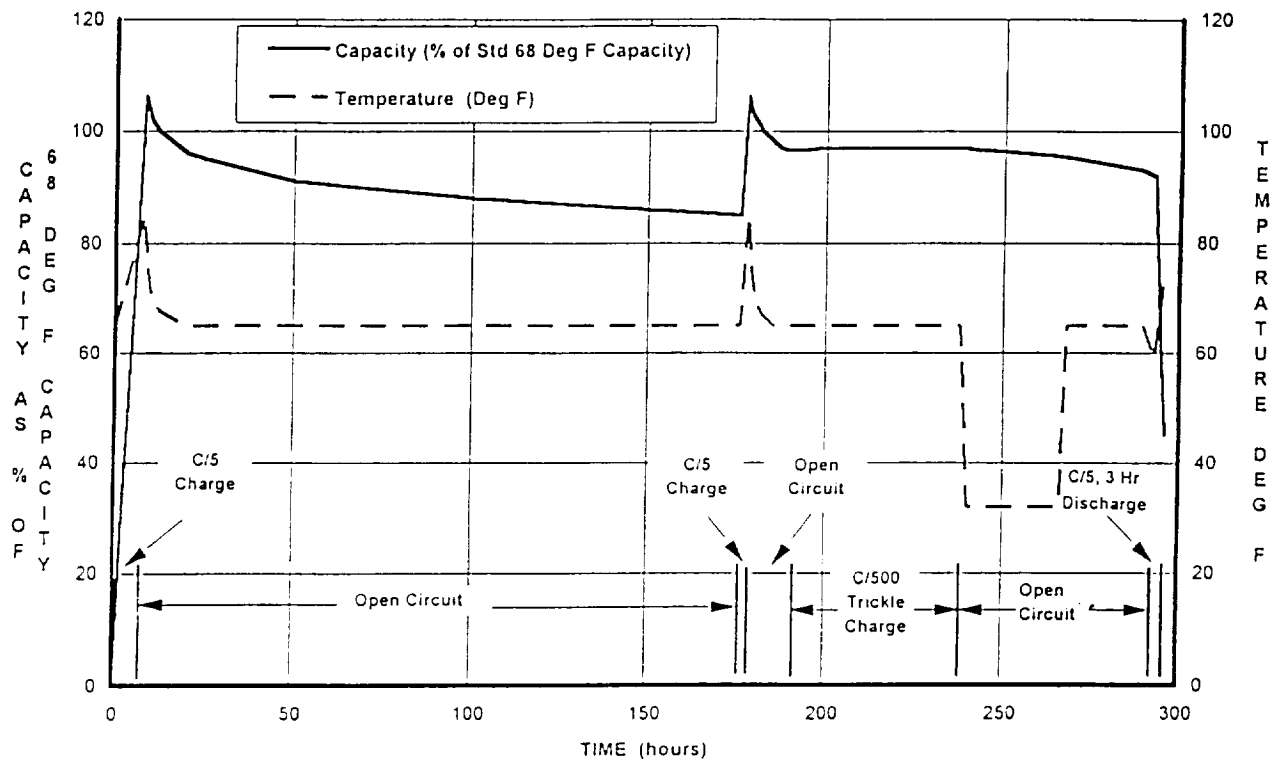
# ADIABATIC CHARGE EFFECT OF THERMAL MASS



Capacity, expressed as per cent of standard 68° F capacity, is plotted against the cell weight/cell capacity figure of merit for initial charge temperatures of 60° F, 65° F, 70° F, and 75° F, and charge rates of C/5, C/10, and C/15. The data is displayed as three sets of curves, one set for each charge rate. Each of the sets of curves consists of four individual curves, one for each initial charge temperature. Inspection of these curves indicates that the impact of the cell weight/cell capacity figure of merit on charge acceptance, in the adiabatic charge mode, is significant at conditions of low charge efficiency, and very small at conditions of high charge efficiency.



# PRE-POST LAUNCH SCENARIO SIMULATION



Adiabatic charging was integrated into a pre-post launch simulation to validate the approach in a mission related scenario. The test cells were charged, from a fully discharged condition, at the C/5 charge rate, with an initial charge temperature of 65° F. Following a one-week open circuit stand at 65° F, the cells were topped off adiabatically at the C/5 charge rate with an initial charge temperature of 65° F. The initial and post top off cell pressures are equal and, after correction for temperature and stored oxygen, the indicated capacities are in good agreement with parametric data base predictions. Following top off the cells were maintained on C/500 rate trickle charge until the simulated launch. The temperature was then decreased to 32° F and held at that temperature for one day. Cell temperature was increased to 65° F and decreased to 59° F as part of the launch simulation. The cells were then discharged at the C/5 rate. Observed capacities are in good agreement with pressure data.

# CONCLUSION

NICKEL-HYDROGEN BATTERIES CAN ACHIEVE HIGH STATES OF CHARGE, IN THE ABSENCE OF COOLING, WHEN CHARGED USING THE "ADIABATIC CHARGING" APPROACH DESCRIBED.